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USER-INTERACTION WITH SELF-LEARNING SYSTEMS (U)

Martin A. Tolcott
Paul E. Lehner
Theresa M. Mullin

DECISION SCIENCE CONSORTIUM, INC.

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HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
HUMAN SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

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FOR THE COMMANDER

CHARLES BATES, JR.
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This research investigated how users interact with an expert system in which underlying values change as a function of the situation or of the planning time horizon. The problem context was the prioritization of tactical air strike targets, and Air Force targeteers were the experimental subjects. Their task was to explain why the system made the recommendations it did. The expert system was simulated in storyboard form. It was found that users who were given a good conceptual model of the expert system, in the form of a brief summary of its step-by-step processes, performed better than those whose model of the system was relatively poor. Users whose displays were relatively "user-oriented" (geographic, top-down, and simplified) did not consistently differ in performance from users whose displays were relatively "aid-oriented" (data-intensive matrices). However, the aid-oriented displays seem to encourage users to make more frequent reference to three tables (available to all subjects) containing important information about the expert

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assessments on which the aid's algorithms operated. Users would typically generate their own solutions, using criteria and heuristics that often differed from those used by the aid, and question the expert system solution. It was concluded that expert system users should be given good conceptual models of their systems, displays that facilitate comparison of a few selected alternative solutions at several selected levels of detail, and alerting messages and data highlighting to bring their attention to values that have changed. The explanation subsystems should be designed to accomplish training as well as explanation.

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PREFACE

This work was conducted by Decision Science Consortium, Inc. as a Small Business Innovative Research project, Phase I, under Contract Number F33615-88-C-0540.

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We are grateful to Jackson O. Crowley, USAF (Ret.) for his help in generating the scenario and obtaining access to Air Force targeteers, and to the Targets personnel at Tactical Air Command, Langley AFB, and at 9th Air Force, Shaw AFB, who patiently served as participants in the exercise.

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1.0 INTRODUCTION

Many federal agencies are investing an increasing amount of money in the development of artificial intelligence (AI) and expert systems technology. This reflects, in part, a desire to reduce the manpower-intensive nature of many tasks by substituting machine intelligence (and energy) where possible, such as in highly structured, fast-paced, repetitive, or dangerous situations. In part, however, it reflects a need to provide assistance to decision-makers in tasks that are relatively unstructured, and not necessarily repetitive, fast-paced or dangerous, but in which people's information processing capabilities are overtaxed. This report deals with the latter case, i.e., the use of AI as an aid to decision making.

AI as a decision aid is particularly relevant to the command and control (C^2) and management settings, because those are settings in which humans are charged with both authority and responsibility, and are therefore reluctant to give up their decision-making role. Whether this role is one of simply monitoring and overriding (if desired) a machine-initiated decision, or of coming to a decision cooperatively with the aid of machine intelligence, will depend on the situational characteristics, but in either case the expert system supplements rather than supplants the human, in the case of interest here.

Currently, the cutting edge of research on expert system decision aids is concerned with self-learning systems, namely, systems that can make significant changes in their knowledge base and their internal processing logic, or rules of behavior, in response either to commands of the user or to external inputs or demands that have been placed on them. It is tempting to think that such systems will be significantly more flexible than conventional non-adaptive systems simply because they are potentially applicable to a more diverse set of situations. However, the potential value of self-adaption must be assessed against the cost of having systems that, from a user's perspective, are constantly changing and therefore difficult to comprehend.

In this regard, three problem areas emerge:

(1) AI decision aids in a C^2 context deal with *cognitive* rather than perceptual or motor functions; cognitive processes are generally understood to involve the structure and representation of information or knowledge, and the rules or logic by which this information is processed to provide a basis for decisions in new situations. These processes cannot be directly observed in humans, and in fact the difficulty of eliciting the knowledge structures and processing rules of experts is one of the chief impediments to the design of expert systems. But an equally difficult problem is that of determining what knowledge and logic inherent in an expert system is needed by a user whose way of thinking about the problem may not match that of the system. In a sense this is the opposite of the expert knowledge elicitation problem, since in this case the system's knowledge must be elicited by, or at least made available to, the system's user.

(2) In an adaptive or self-learning system the problem is compounded by the dynamic nature of the system's expertise. Thus, new information that has been incorporated into the system's knowledge structure, and new or modified rules for processing the information, may have to be brought to the attention of the user rapidly, when appropriate, in order to up-date the user's understanding of the system and maintain his confidence in its outputs. Except for some research (to be discussed later) on the differences between experts and novices in how they form mental models, there is very little understanding of the evolution of knowledge structures or, more importantly, what significant changes must be brought to the attention of the user of a self-learning expert system.

(3) Underlying both of the above issues is the requirement for an effective (or "friendly") interface between the system and its user. An effective man/machine interface involves more than simply an easily understood method of interacting (although it certainly requires that). Cooperative problem solving between an expert system and its user requires the ability to rapidly request and obtain information, share knowledge and provide prompts, at the initiation of either the system or its user. Furthermore, if the user's confidence in the system is to be maintained, the system must operate in a way

that is predictable by its user. This is not to say that the expert system's recommendations must be anticipated, but rather that the system's problem solving procedures must be predictable so that the user can interact easily (i.e., be able to interrupt with requests or overrides, be prepared for system requests) in order to achieve a truly cooperative approach to problem solving. Methods of implementing these requirements have barely been covered in the literature on human/machine interaction.

In summary, in order for self-learning systems to achieve their full potential as decision aids, ways must be found to determine the information needs of their users and to provide their users with dynamic, on-line up-dating of a changing knowledge base and logic, and with interactive techniques that ensure effective cooperative problem solving.

As a promising approach to this problem, this research seeks advances in both the theory and application of mental models and human knowledge representation. Regardless of how knowledge and processing rules are represented within AI systems, their understanding by a user will depend on the ease with which they can be absorbed into the user's cognitive framework. The research reported here explores how this may be accomplished.

2.0 HUMAN KNOWLEDGE REPRESENTATION

Research on how humans organize or represent knowledge has been prompted by a variety of motives, all of which relate to the ultimate improvement of human reasoning and problem-solving performance. Some of the research, described in Kahneman, Slovic and Tversky (1982), has investigated typical heuristics or short-cuts in the reasoning process that lead to biases or errors in judgment; this work is motivated largely by an interest in helping people to avoid violations of rational or prescriptive models, either through training or computer-based aids. Some developers of artificial intelligence systems have sought to design those systems to emulate human information processing structures, in order to achieve the speed and efficiency shown by humans under certain conditions (e.g., the parallel processing capability of neural networks). Still another line of research has investigated differences between the cognitive structures and processes of experts as compared with novices, in order to find ways to design instructional systems that can bring novices to expert levels more efficiently. The several lines of research have produced a variety of categorization schemes that reflect different theories about how people represent or form mental models of knowledge. These schemes are described and interpreted in this section.

2.1 Declarative vs. Procedural Structures

One common scheme for categorizing knowledge structures, described by Madni (1988), is that of declarative and procedural representations. Declarative structures refer to the representation of facts ("data") or assertions (logical relations); they are often further subdivided into relational structures such as semantic networks, and logical structures such as production rules, frames and scripts, although production rules have also been viewed as procedural. Procedural representation, on the other hand, can be characterized as a prescription for a set of actions; procedural knowledge consists of knowledge about what to do in specified situations. Anderson (1982) has viewed the achievement of expertise as the replacement of a declarative mode of knowledge representation by a procedural mode. In this view, novices build up a declarative or factual base of knowledge, and learn a set of analytical tools for operating on it. Their problem solving tends to

be relatively elaborate, laborious and time-consuming, the level of understanding is superficial rather than deep, and their ability to generalize to other situations is limited. Declarative knowledge has also been termed "propositional," by Rumelhart and Norman (1985), among others, who describe it as a set of discrete symbols, propositions, or formal statements. As expertise develops, the factual knowledge becomes transformed into a set of procedures that can be brought to bear quickly and intuitively in a variety of situations (Madni, 1988). Such knowledge is characterized by Rumelhart and Norman as knowledge of "how" rather than "what," and they include production rules in this category.

Using this categorization scheme, the problem solving of novices is seen as the application of analytical methods to a body of facts and relationships, while that of experts tends to be a more intuitive, relatively automatic, invoking of a set of procedures appropriate to situations with common characteristics. In research comparing analytical with intuitive styles of decision making, Peters, Hammond and Summers (1974) found that although analysis results in greater accuracy on the average, extreme errors can occur with a significant probability, while intuitive thinking results in a flatter distribution of performance (a preponderance of approximately correct responses) but with relatively few extreme errors.

2.2 Interpretative vs. Generative Structures

Another theoretical approach views knowledge structures as either interpretative ("top-down") or generative ("bottom-up"). Perhaps the most dominant of the interpretative theories is that of Schank, Abelson and their colleagues (Cullingford, 1978; Schank, 1982; Schank and Abelson, 1977) based on the concept of schemata or frames. They posit a hierarchical knowledge structure that provides for the interrelation and relative importance of pieces of knowledge, with slots at each node in the hierarchy corresponding to pieces of knowledge expected to fill that slot. The slots serve as sources of expectancies as to what information will be encountered. The hierarchical organization implies a top-down manner of processing and representing information, i.e., focus will be on the higher, more important goal-directing elements which in turn will determine the organization of the lower, less

important elements. Schank (1982) has emphasized the goal-directed character of memory organization in his concept of Memory Organization Packets (MOPs), which he describes as a set of scenes directed toward the achievement of a goal. A scene common to several situations serves as an index from one situation to another, thereby fostering generalizations.

On the other hand, generative structures are characterized by knowledge organization driven by lower level facts, rules or relationships, such as production rules, or semantic networks. It seems reasonably clear that the data-driven character of generative structures has much in common with the declarative/analytic representation attributed to novices, while the goal-directed character of interpretative structures is similar to the procedural/intuitive representation attributed to experts.

2.3 Analogical Mental Models

The literature on mental models significantly overlaps that on knowledge representation, and the two concepts are often referred to interchangeably. However, two distinctions that have been drawn are that (1) a mental model bears a close structural isomorphism (e.g., spatial, temporal) with the phenomenon or system it represents (Johnson-Laird, 1983), and (2) it should be "runnable" in the sense that a person should be able to modify the inputs or relationships mentally and determine how the outputs would be affected (Williams, Hollan and Stevens, 1983). Another feature commonly ascribed to mental models, although not in distinction to knowledge structures, is that their components may be decomposed to more detailed levels or aggregated to broader levels of abstraction.

The concept of a runnable mental model that can be used to diagnose reasons for a current state of affairs or to predict future conditions, bears a close resemblance to the type of knowledge structure described above as declarative, analytical, or generative. However, it is generally acknowledged that as one becomes familiar with a class of problems (i.e., as one approaches expertise) one can use a briefer version of the model in which a set of conditions immediately implies the appropriate outputs, thus appearing to behave much like an intuitive knowledge structure. In fact, Klein (1989) has emphasized

the role of analogical or recognition-based reasoning, that allows experienced problem-solvers to recognize key aspects of a situation and respond very rapidly, in contrast to the more rigidly formal analytical processes underlying many types of decision aiding systems. Klein's research suggests that analogical decision making is most appropriate when what is wanted is a reasonably satisfactory rather than an optimum solution, which is consistent with the findings of Peters, Hammond and Summers (1974) described earlier.

2.4 Experts vs. Expert Systems

The research reviewed above suggests that when experts are solving a problem manually, their knowledge structure or model of the problem is quite different from that of a typical expert system that might be provided as a decision aid. The expert's view of the problem would tend to be analogous to the problem domain, reflecting its spatial or temporal features, and his or her approach would tend to be top-down or goal-driven and characterized by a relatively simplified set of heuristics or "intuitions," triggered by recognized features of the situation that have been learned over a long period of time. The expert's knowledge would be deep enough to permit rapid generalization to new situations. On the other hand, decision aiding systems tend to be data-driven and therefore data-intensive, relying heavily on algorithmic or analytical procedures that seek optimum solutions. This discrepancy in knowledge structures and procedures has frequently led to the rejection of decision aiding systems by experts, and is responsible for a substantial current interest in finding ways to design such systems with user needs in mind.

2.5 Research Issues

Although it appears obvious that the user's mental model or knowledge structure should be a driving force in designing interfaces with expert systems, there has been surprisingly little research on this issue. It is not clear, for example, whether interface design should be tailored to the way the expert user views the problem (regardless of the system's knowledge structure), or whether efforts should be focused on ensuring that the user is given an accurate model of the structure and functioning of the system itself. One study, conducted by Lehner and Zirk (1987), examined problem solving

performance by a human and an expert system in a cooperative mode. Cooperation was forced by the fact that neither party alone had access to all the data. One key variable was the consistency of the problem solving procedures by the system and its user. The other key variable was the accuracy of the mental model that the human had of the system. Under one condition, the human was given no model of the system; in the "accurate cognitive model" condition subjects were instructed about inference networks in general and were shown a pictorial display of an inference net and a simple example of its operation, which induced a cognitive model of how the expert system solved problems. The results showed that, regardless of the consistency of the procedures used, performance was better when the user had a good cognitive model of the system's procedures. In fact, under the "accurate cognitive model" condition, performance was better when the user and the system were *inconsistent* rather than consistent in their procedures. These results suggest that expert systems and humans can indeed complement each other by using different problem solving methods, provided that the human understands the basis on which the system reaches its conclusions. Implied in these results is the importance of notifying the user rapidly of any changes in the system's procedures that might affect the cooperative interaction. Lehner and Zirk used a set of written instructions in their experiments, but clearly in the case of a self-learning system the information would have to be developed internally by the system and presented by means of an appropriately designed user interface.

One of the limitations of Lehner and Zirk's study was that the subjects were not experts in the usual sense of the term. The task was a relatively simple one that could be learned in a brief training session, and in that sense the subjects could not be considered novices. However, expertise is usually characterized by years of experience dealing with many variants of the same type of problem, and the development of a relatively stable view of the problem domain and set of preferred procedures and heuristics for solving it. These were not characteristics of the subjects in their study.

The question remains, therefore, as to the most appropriate approach to designing interfaces between an expert user and an expert system, namely, whether to base the design on the user's mental model of the problem domain,

or to attempt to foster a good mental model of the expert system itself. Indeed, recent research by Roth, Bennett and Woods (1987) suggests the importance of a shared frame of reference for the user and the machine aid. These authors stress the importance of explicitly representing to the user the machine's perception of the status of the problem it is attempting to solve. Moray (1987), on the other hand, argues that operators of systems acquire mental models of these systems that are "homomorphs" of the original system, by which he means reduced or simplified versions (partial models) as contrasted with isomorphs or exact models. He advocates that intelligent decision aids intended to help operators control systems should be based on these homomorphs.

The research reported here is an attempt to explore these issues in a military decision making context. The problem domain is that of the prioritization of targets for tactical air strikes, during which a simulated expert system develops a recommended target priority list and the expert user's task is to determine why the system developed the list that it did. Specifically, the research explored the issues of (1) whether it is more important for displays to be compatible with the user's or the aid's model of the problem, and (2) the extent to which the displays affect performance when the user has or does not have a good mental model of the aid.

3.0 PROCEDURE

3.1 General

The general procedure was to ask Tactical Air Force targeting specialists to work on a targeting problem, except that instead of generating a target prioritization list they were to examine a strike plan generated by a simulated Target Prioritization Tool (TPT), and answer some questions designed to measure how well they understood why the TPT generated the list and plan that it did. All the participants were given the same mission guidance (to achieve air superiority in the area of interest in three days) and the same scenario (enemy air order of battle). They differed in (1) whether they were provided with a relatively good or relatively poor model of how the TPT worked, and (2) whether they were provided with available displays that were relatively user-oriented or relatively aid-oriented. Thus, the experimental design consisted of four cells, as shown in Figure 3-1.

Good aid model User-oriented displays	Good aid model Aid-oriented displays
Poor aid model User-oriented displays	Poor aid model Aid-oriented displays

Figure 3-1: Experimental design.

The computations leading to the TPT recommendations were based on the types of data and algorithms utilized in a Target Prioritization Aid (TPA) developed by PAR (in conceptual form) for Rome Air Development Center (reference). All participants were briefed on how the TPT worked. Those who were in the "Good aid model" groups were given, in addition, a one-page summary of the step-by-step procedure followed by the TPT in reaching its conclusions, while those in the "Poor aid model" groups were not given this summary. Those in the "User-oriented displays" groups were given displays based on an expert consultant's description of how targeteers do their job; these displays

included maps of the area of interest showing 16 enemy air bases (possible targets) with their aircraft (types and numbers), and more detailed information about each base and its installations (Air Installation Data) in tabular form, base by base. This was consistent with the concept of an expert's mental model of the problem as geographic, top-down, and simplified. Participants in the "Aid-oriented displays" groups were given the same information in matrix form, each matrix providing data on all enemy bases in the same table. This was consistent with the internal structure of the TPT as a data-intensive, algorithmic optimizer. The TPT performs several functions based on values that had been furnished by experts during the development of the Target Prioritization Aid. It estimates the potential sortie generation rate (the threat) for each enemy airbase, based on type and number of aircraft and distance from the area of interest. It estimates the reduction in sortie generation rate that could be achieved by one or more successful attacks on specific airbase components such as unsheltered aircraft, revetments, maintenance facilities, etc. (the benefit). It estimates the number of friendly strike aircraft required to attack those components (the cost). It calculates the benefit/cost ratio for attacks on those components, aggregates these values across components for each airbase, prioritizes the potential targets according to these values, generates a prioritized list of targets and specifies the components to be hit at each base. All participants were provided with the "knowledge base" of the TPT, that is, the expert assessments on the basis of which the threats, benefits, and costs were estimated, and the aggregated benefit/cost ratio for each target. The "Good Aid Model" subjects were given, in addition, the one-page summary of the aid's processes, as shown in Figure 3-2.

The TPT was simulated in storyboard form. The displays available to participants were presented as hard-copy pages in a notebook, with the pages tabbed for ease of retrieval. Prior to each experimental trial, the participant was "walked" through the notebook and each available display was explained.

In the actual experimental trial, the participant was given the "output" of the TPT, consisting of the prioritized target list and components to be hit at each base, for each of three successive days of attack. The three highest

DESCRIPTION OF AID PROCESSES

The TPT determines the priority of targets by proceeding through the following steps.

1. **Calculate # Sorties of Interest** - Calculate the number of sorties of interest that each airbase can generate per day.

2. **Calculate Effects** - For each component of each airbase calculate (using the database of Expert Assessment of Effects) the percent reduction in air base capacity that would be achieved by attacking that component either once or twice.

3. **Calculate # Sorties Reduced** - Multiply the above two numbers to determine the number of enemy sorties that would be reduced by hitting each component of each airbase.

4. **Calculate Friendly Sorties Req'd** - Calculate the number of friendly sorties (F-16 and F-111s) required to attack each component of each airbase.

5. **Calculate Component Benefit-to-Cost Ratios** - For each component of each airbase calculate a benefit-to-cost ratio by dividing the number of enemy sorties reduced (step 3) by the average number of friendly sorties required (step 4). A separate value is calculated for hitting the component either once or twice.

6. **Determine Plan of Attack** - Select for attack the components (of any airbase) with the highest benefit-to-cost ratios. Select enough components to use more than 300 F-16 sorties in a ground attack role. This is the overall proposed Plan of Attack.

7. **Calculate Benefit-to-Cost Ratio for each airbase** - For each airbase 0 or more components will have been targeted in the Plan of Attack. For each airbase, calculate the total benefit-to-cost ratio for hitting all the components targeted in the Plan of Attack.

   This benefit-to-cost ratio is the target value (priority) assigned to an airbase.

Figure 3-2. Description of Aid Processes.

priority targets on each day were identified (they were not necessarily the same targets each day), and the task for the participant was to select, from a list of possible factors, those that made a significant contribution to the high value of the top three targets, and to rank the components hit at each target (they were not necessarily the same) in order of their importance to that target's high value.

Appendix A presents the instructions, guidance, and response forms given to all the subjects; the instructions and guidance were read to them as well as being provided in written form. Appendix B presents the displays made available to the User-Oriented Displays Group. Appendix C presents the displays made available to the Aid-Oriented Displays Group.

In addition to the performance measures, a tabulation was made of the frequency with which each display was referred to. Finally, at the end of the session, each subject was asked which displays were found particularly helpful, what other displays would be desirable, and how in general a computerized aid could help in the targeting task.

A pilot study was conducted at Headquarters, Tactical Air Command, Langley Air Force Base with four Targets personnel, each of whom was available for two 2-hour sessions on two successive days. It had originally been intended to present two problems in each session, with changed values in the expert knowledge base or the enemy AOB, to determine how well the changes could be detected. However, the task proved to be more difficult than expected. Consequently, the procedure was simplified by presenting only one problem and relying on the changes in the TPT's recommendations over the three-day strike planning period to determine how well the TPT's basis for target prioritization could be understood. As a result of the pilot study certain changes were made in the response sheets to simplify and shorten the time needed to record responses. The analysis is based on results obtained one week later, with 8 Targets personnel at 9th Air Force, Shaw Air Force Base.

3.2 Air Force Participants

The four Targets personnel at Langley AFB were from the Directorate of Intelligence Application, Targets Division (INAT); they included two Majors, a Technical Sergeant and a Staff Sergeant whose years of experience doing targeting ranged from 0-15 years. These participants contributed significantly to the project by:

- Providing a clearer understanding of the problem domain which in turn permitted the development of improved displays and test methodology;
- Providing the expertise, advice and guidance that allowed us to proceed to Shaw AFB with a proven test plan;
- Facilitating the arrangements for participants at Shaw AFB.

The 8 Targets personnel at Shaw AFB were from the 9th Air Force's Tactical Intelligence Squadron, Targets Branch; their experience doing targeting ranged from 2-12 years, with a mean of 4.8 years. All the participants at both locations were extremely cooperative.

4.0 RESULTS

Described below are the results for the eight participants from Shaw AFB. The determination that the Langley experiment would be treated as a pilot study was made prior to any data compilation or analysis.

4.1 Performance Analysis

For each of the top three priority targets, for each day, subjects were required to (1) select from the List of Factors those factors that led to a target receiving a high priority and (2) rank order the target components selected for attack by their contribution to the overall target value. For both of these assessments correct answers were derived (see Appendix D). Determining the "correct" answer involved some judgment on our part. However, the assessment of the "correct" answer was made prior to any examination of the data.

4.1.1 Selection of factors. For each day, each factor was coded as either "Yes" (clearly a factor), "No" (clearly not a factor), or "Uncertain" (intermediate range). For instance, Factor 2 was "Airbase contains relatively more enemy a/c of interest." Each airbase had either 45, 30, 15, or 0 aircraft of interest. If the airbase had 45, Factor 2 was labeled "Yes;" 15 or 0 it was labeled "No;" and 30 it was labeled "Uncertain." For each high priority target on each day we determined the number of "Yes" or "No" factors correctly identified. For instance, for airbase Mimon on Day 1 there are three "Yes" and two "No" factors. If a subject listed as important two "Yes" factors and one "No" factor, then he or she received a score of 3 out of 5. Note that mathematically, Factor 5 is derived from and redundant with Factor 4. Consequently, rather than double count the same factor, it was dropped from consideration prior to any data analysis.

After recording the scores, we realized that Factor 7 was (unintentionally) deceptive. As it turns out, it is inherent in the nature of the TPA algorithm that Factor 7 must always be answered "No," no matter what targets are selected. This was a subtle point, and nearly all the subjects

inappropriately added Factor 7 to their list of factors. We performed the analysis both with and without this factor.

Data for each subject, and totals, are found in Tables 4-1 through 4-5. Table 4-1 shows the total number of factors correct by cell. Table 4-2 shows identical data to Table 4-1, except that Factor 7 was dropped.

Table 4-1: Number of Factors Correctly Identified
(Out of 43)

Conceptual Model	Display: User-Oriented		Display: Aid-Oriented		Totals
Good	S #1	28	S #2	27	
	S #8	19	S #7	37	111
		47		64	
Poor	S #4	21	S #3	33	
	S #5	25	S #6	17	96
		46		50	
Totals		93		114	

Table 4-2: Number of Factors Correctly Identified, Excluding Factor 7
(Out of 34)

Conceptual Model	Display: User-Oriented		Display: Aid-Oriented		Totals
Good	S #1	28	S #2	26	
	S #8	19	S #7	32	105
		47		58	
Poor	S #4	21	S #3	29	
	S #5	19	S #6	17	86
		40		46	
Totals		87		104	

With only two subjects per cell, and a wide variation between subjects, a by-subject statistical analysis of proportion correct will not result in any statistically significant results. To determine whether or not there was any

discernible difference between the Good vs. Poor Conceptual Model conditions and the User- vs. Aid-Oriented Display conditions, a Chi-square analysis was performed on the overall number correct per cell. For Good vs. Poor Conceptual Model the p-levels were $.35 > p > .3$ and $.25 > p > .15$ for Tables 4-1 and 4-2, respectively; thus the good conceptual model resulted in slightly but not significantly better performance. For User- vs. Aid-Oriented Displays the p-levels were $.2 > p > .1$ and $.25 > p$ $.2$ for Tables 4-1 and 4-2, respectively; with the aid-oriented displays resulting in slightly but not significantly better performance. The best single condition was Good Conceptual Model combined with Aid-Oriented Displays.

4.1.2 Prioritization of components. To determine the correct priority of the components, we calculated the benefit/cost ratio for each component (using information available to the subjects) and ordered the components according to this ratio. We compared the subjects' ranking to the correct ranking by decomposing each ranking into separate pair comparisons and then recording the proportion of pair comparisons the subjects ordered correctly. This procedure is conceptually similar to Kendall's Tau measure, but allows us to aggregate the data from multiple rank orders.

After scoring the subjects, we noticed that the TPA algorithm invariably assigned a high benefit/cost ratio to the component "Unsheltered Aircraft" whenever the Air Installation Data indicated there were only one or two unsheltered aircraft at the air base. Consequently, for this component the TPA algorithm was in direct contrast to any reasonable answer. For this reason we analyzed the data with and without this component.

Tables 4-3 and 4-4 present the data by cell. The Good vs. Poor Conceptual Model results were similar to the selected-factors data. The User- vs. Aid-Oriented Displays results were reversed. Subjects with user-oriented displays performed better. Here the best single condition was Good Conceptual Model with User-Oriented Displays.

Table 4-3: Number of Pairs of Components Correctly Ordered (Out of 55)

Conceptual Model	Display: User-Oriented		Display: Aid-Oriented		Totals
Good	S #1	43	S #2	26	
	S #8	29	S #7	32	130
		72		58	
Poor	S #4	20	S #3	31	
	S #5	35	S #6	21	107
		55		52	
Totals		127		110	

Table 4-4: Number of Pairs of Components Correctly Ordered, Excluding Unsheltered A/C (Out of 35)

Conceptual Model	Display: User-Oriented		Display: Aid-Oriented		Totals
Good	S #1	26	S #2	22	
	S #8	21	S #7	21	90
		47		43	
Poor	S #4	18	S #3	21	
	S #5	22	S #6	16	77
		40		37	
Totals		87		80	

As above, we performed a Chi-square analysis on the total-number-correct per condition. For the Good vs. Poor Conceptual Model difference the p-levels were $.2 > p > .1$ and $.4 > p > .3$ for Tables 4-4 and 4-5, respectively. For the User vs. Aid-Oriented Displays the p-levels were $.35 > p$ $.25$ and $p > .5$ for Tables 4-3 and 4-4, respectively.

4.1.3 Summary of performance analysis. We also examined the correlation between rank and years of experience with this performance data. No correlation between performance and these variables was discernible.

Overall the only reliable effect seems to be for the Good vs. Poor Conceptual Model difference. Performance in the Good Conceptual Model groups were generally higher than performance in the corresponding Poor Conceptual Model groups. Note, however, that although the Chi-square tests indicate some marginally significant results, the observations could hardly be considered independent, since each subject contributed multiple data points. In short, although these tests do indicate a possible effect for the Good vs. Poor Conceptual Model conditions, the analysis does not allow us to attribute the effect uniquely to the experimental manipulations.

4.1.4 Pattern of use of displays. Of interest is whether the differing conditions impacted the displays which the subjects examined while solving the experimental problems. Of particular interest is the extent to which subjects used the Expert Assessment (Knowledge Base) displays to solve the problems. For each subject, we recorded the number of times they examined each display. Table 4-5 indicates, for each subject, the number of times a subject examined any of the three Expert Assessment displays and (in parentheses) the total number of times attention was shifted from one display to another. In general, the Aid-Oriented Displays group examined the Expert Assessment displays far more frequently than the User-Oriented Displays group. A t-test comparison resulted in p-levels of $.1 > p > .05$ (two-tailed) for both proportions and absolute numbers.

Table 4-5: Number of Times Any of the Three Expert Assessment Displays was Examined

Conceptual Model	Display: User-Oriented		Display: Aid-Oriented		Totals
Good	S #1	2 (105)	S #2	37 (159)	
	S #8	43 (195)	S #7	31 (201)	
		45 (300)		68 (360)	113 (660)
Poor	S #4	1 (109)	S #3	40 (183)	
	S #5	0 (157)	S #6	45 (148)	
		1 (266)		85 (331)	86 (597)
Totals		46 (566)		153 (691)	

Note that unlike the Chi-square tests above, the t-test treated each subject as a single data point. Consequently, statistical differences between the two conditions could be reasonably attributed to the experimental manipulations. (Note however that this test was determined a posteriori.)

4.1.5 Effect of display use on performance. Although participants with the aid-oriented displays tended to use the Expert Assessment tables more than those with the user-oriented displays, an interesting question is whether the use of these displays affected performance, for better or worse. No statistical analysis was justified with only 8 subjects, but an examination of the scores and frequency of use data was made. It turns out that of the four subjects who referred to those displays most frequently, two scored highest and two scored lowest on the Identification of Critical Factors, and there was no discernible trend in the Ordering of Components. Thus, although several of the participants commented that these tables were useful, there is no evidence that performance was significantly improved by frequent reference to them.

4.2 Qualitative Comments

It had been anticipated that those subjects in the User-Oriented Display groups would make frequent reference to map displays available to them, since currently targeteers rely heavily on map displays. Contrary to expectation, the map displays were almost never referenced. Most of the participants recognized the value of tabular data for solving the task they were given, especially since the matrices allowed them to compare characteristics of all possible targets very quickly. Only one participant expressed a preference for an "ideal" set of displays that would promote a top-down approach: a map of the total situation (bases, distances and sorties), as well as individual tables with details that could be selected as desired.

Another class of comments suggested disagreements with the criteria used by the TPT to prioritize targets. The most fundamental was the objection to use of sortie reduction rate as the primary criterion (despite the Commander's Guidance which established the goal of air superiority in three days). One subject commented that friendly forces should inflict as much damage as possible, implying that a procedure based on aggregated benefit/cost ratios

would not be the accepted procedure in the field. Other participants apparently did not appreciate the TPT's selection of components based on effects two or three days in the future; they would have hit aircraft in the open or in shelters immediately, ignoring the short-term effects of that strategy as compared with the longer-term effects of hitting other components. The value of hitting command and control facilities immediately was justified by reference to their critical importance in view of the enemy's hierarchical structure and the immediate (if indirect) effect of their loss to enemy operational capability.

Such comments are important even beyond their application to the type of expert system hypothesized in this study. They suggest that users of expert systems must be informed not only of numerical values, generated by experts, that go into algorithmic computations, but also of the rationale underlying these judgments. The user of such a system should use its recommendations as one source of information--all the participants agreed with that concept. They should be able to disagree, based on either general or situational differences. But it is important to be able to identify the source of disagreement quickly in order to take effective action, and to achieve this the user needs more information about the expert system than was provided in this exercise.

5.0 DISCUSSION OF RESULTS

The results of this research are only suggestive. The task presented to the subjects was relatively difficult, and the subjects, although currently assigned to an appropriate office, did not have as much experience in targeting as we had hoped (with one or two exceptions). There were only eight subjects, and they differed widely in experience. Only two hours were available to explain the problem, describe the aid and displays, present the scenario, and work the problem. With so much material to be absorbed before starting the problem, the group receiving the "good" conceptual model of the aid (a one-page summary of its step-by-step procedures) might not have had much advantage over the "poor" conceptual model group. The three displays considered most important for understanding the aid's reasoning were common to both the Aid-Oriented and User-Oriented Display group.

On the other hand the participants in this study may well have been typical of the users of an expert targeting system and, in fact, of military expert systems generally. Very senior personnel with broad experience would probably have moved up in the chain of command to relatively more supervisory positions, while the expert system would have been designed as an aid for middle-level personnel with relatively less experience. What may be inferred from the results of this experiment is that such a group of expert system users are likely to be highly variable in their type and extent of operational experience, and that therefore the system must be designed with a wide range of user capabilities in mind. In fact, for many users the system should serve the dual purposes of decision aiding and training, and the training function should be aimed not only at teaching users how the system works but also at providing them with an opportunity to practice solving the relevant problem under a variety of situations.

The discussions following each session were revealing of both the problems faced by the participants and the paths toward their solution. It was clear that targeteers have their own ideas of the target characteristics that contribute to high priority. These may vary among individuals, and they certainly may vary from those of experts whose views have been solicited as a

basis for design of an expert system. If the expert system data or model change as a result of changes in the situation, or if its recommended plans over a period of time are based on time-varying criteria of effectiveness, the rationale for its recommendations must be clear to the user so that differences of viewpoint can be quickly identified and easily acted upon. In this study the time-varying effectiveness criteria were presented in a numerical matrix display, the aid's criteria had been explained to all participants, and the "good" model group had an additional one-page summary. This was insufficient for purposes of the task presented to these subjects in the time available.

What would be desirable in an actual expert system would be an explanation capability that operated on a query-response basis, allowed the users to seek explanations at various levels of detail, and made it easy to compare their own solutions with the recommended ones. For example, during their problem solving sessions, participants thinking aloud would typically make remarks such as: "I don't understand why (Target X) has such a high priority; I would have selected (Target Y);" or "I would always hit unsheltered aircraft." An expert should be able to compare the factors comprising the score of his own choice with those comprising the score of the recommended choice, so that he can determine whether or not to accept the recommendation; for a less-than-expert, the comparison would be beneficial as a training aid.

In more general terms the findings of this study suggest that a self-learning system, or one in which values change as a function of the planning time-horizon, should have certain features to facilitate both explanation and training. These features are described below.

5.1 Good Conceptual Model of the Expert System

In all the performance comparisons, participants who were given a brief summary of the aid's sequential processes (i.e., who had a relatively good conceptual model of the aid) did better than those who were not given this summary. This is consistent with the findings of Lehner and Zirk (1987), and reinforces the importance of ensuring that the user of a system has a good

mental model of the system, regardless of his model of the problem domain. In the present study this system model was presented simply in the form of a series of narrative paragraphs. In other contexts (and perhaps even in the present context) other representations such as graphic function flow diagrams or network diagrams might be even more effective. The most appropriate format will depend on the characteristics of the system being portrayed, but in general a graphic representation is likely to be more effective than a textual one.

5.2 Display Orientation

There was no evidence that user-oriented displays (maps and individual target data sheets) resulted in either better or worse performance than aid-oriented displays (data matrices). The aid-oriented displays furnished significantly more information in a single table, obviating the need to scroll through a series of tables to compare the characteristics of several targets, and therefore should have been preferable. In an actual system there would be no reason not to have both types of format available, to be selected at the option of the user.

The one significant difference between the two display types was that the aid-oriented displays apparently encouraged users to refer more frequently to the expert assessment tables, which contained information essential to accurate performance. However this difference did not result in better performance. It is likely that better performance would have resulted if the explanatory subsystem had been more effectively designed (see below), but the results offer no basis for preferring one type of format over the other.

5.3 Comparative Method of Explanation

As noted earlier, the participants typically worked through the targeting problem using their own criteria and heuristics, compared their results with the aid's recommendations, and then sought an explanation for the differences. Although much of the needed information was expressed in the benefit/cost calculation for each target as well as the expert assessment tables of enemy

threat, costs of friendly attack, and effects, these tables were not designed specifically to foster direct comparison of a few cases presented in close proximity, as an interactive system could do easily. Displays that allowed users to select two or more cases for direct comparison at various levels of detail (see below) would be compatible with the procedures used by the participants in this study.

5.4 Hierarchical Structure

Combined with the comparative method of explanation, a hierarchical structure is recommended that would allow the user to compare explanations at various levels of detail. Thus, at the highest level in the target prioritization problem, the user might select his own highest priority target for comparison with the aid's top one, two or three recommendations, and ask to see simply the benefit/cost ratio for each. He might then call up a listing of the next-level factors that go into this computation (enemy sorties available, sorties reduced, and cost), for a rapid comparison. More detail could be sought by examining the components of each target, the sortie reduction effects and the costs of attacking each component. Finally, if desired, the user could call up the equation or algorithm used by the aid to determine its priorities.

5.5 Time Dependencies

For an expert system that adapts to a changing situation, or one whose values change with the planning time-horizon, the relevant time-dependent values must be made very evident to the user. In this study the value of attacking various target components changed as the planning horizon changed from three, to two, to one day before the effect was desired. The Expert Assessment of Effects table showed these changing values for each type of target component, but the participants apparently missed or disagreed with the time-dependent effects, or simply mis-read the table despite its being explained to them. For the problem posed in this study, it would be desirable for the user to enter the planning day of interest and have the relevant data in the table highlighted to attract the user's attention. Similarly, highlighting could be used in a self-learning system to call a user's attention to data or values

that have changed as a result of a changing situation. In the latter case an alerting message would be appropriate any time a change occurred to make sure the user is aware of a change; the highlighting would remain on each display with relevant data until the user has called it up once, or until a new change has occurred.

6.0 CONCLUSIONS

On the basis of experimental findings, the following conclusions are derived:

For users of an expert system, a good conceptual model of the system is more important than displays that are consistent with the users' model of the problem (geographical, top-down and simplified). Displays that are relatively aid-oriented (data-intensive matrices) are just as effective, and tend to encourage users to refer to underlying expert assessments, values on which the aid's algorithms operate.

Expert system users may apply criteria and heuristics that differ from those of the experts whose knowledge is represented in the system. The aid should be designed to allow users to compare their solution with the aid's recommendations, to facilitate learning as well as to provide a clear basis for experienced users to disagree with the aid's recommendations and substitute their own.

The aid's explanation subsystem should be structured hierarchically, to permit comparison of alternative solutions at several different levels of detail.

In a self-learning system, or one whose values change with the situation or with the planning time-horizon, it is important to alert the user to the fact that a change has occurred and to highlight the data that have changed, at all levels in the explanation hierarchy.

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APPENDIX A

INSTRUCTIONS AND GUIDANCE GIVEN TO ALL PARTICIPANTS

GENERAL INSTRUCTIONS

Introductions.

We represent a company, Decision Science Consortium, under contract with the Armstrong Aerospace Medical Research Lab at Wright-Patterson Air Force Base. The purpose of our research contract is to investigate how people interact with self-learning expert systems, that is, decision aiding systems that may adapt to changes in an evolving situation. We are not promoting the development of such a system. But there is a lot of R&D being conducted on various types of decision aids and our concern is to help make sure that if they are developed for operational use, they are designed to meet the needs of their users.

I want to assure you that this exercise is not a test of your performance. We want to get some information about your background to help us interpret the results, but the data that we get during the exercise will be treated in the aggregate, and no names will be used in our report.

We have chosen the tactical air strike targeting problem as the context for this research--again, not because we are promoting an expert system for this task but because there has been some previous work on a target prioritization aid and we are familiar with it. In addition, Jack is a retired TAC officer with operational experience in a TACC, and he can answer any of your questions dealing with the scenario that we have generated.

For purposes of this exercise we will ask you to play the role of a targeteer in a TAC Headquarters in Central Europe. But instead of generating target recommendations, we will ask you to assume that there is an expert system that processes available data and presents these recommendations to you. Your task in this exercise is to figure out why the system generated the list that it did.

We will set the stage with an initial scenario that is fairly typical of tactical air operations in the European theater. After you get the system's recommended target list, you will have several data displays available in this notebook to help you figure out the reasons for the recommendations. We are interested in seeing which of these displays you use, which you find most helpful, and why. If you can think aloud while you are solving the problem, that would be most helpful. When you think you have completed the task, let us know. We will ask you a few more questions at that time.

We have allowed two hours for the exercise. We think this is enough time for the problem, but we don't want you to rush through it.

Finally, we would appreciate your not discussing this exercise until we have completed all the sessions. Do you have any questions about the procedure?

COMMANDER'S OBJECTIVE STATEMENT

The CINCENT objective is to attain localized air superiority over the area of Fulda and Hannover in three days so that on "Day-4" maximum emphasis can be placed on Offensive Air Support. COMFOURATAF is requested to undertake this task.

A. In response to Soviet-Warsaw Pact aggression, which includes incursions into NATO's Central Region and the occupation of West Berlin, the Ministers of Defense through Hq SHAPE have granted unrestricted cross-border authority for conventional offensive operations against East Germany, Czechoslovakia, Poland, and the Western military districts of the USSR. Cross-border activity will commence on "Day-1". Attainment of localized Air Superiority over Fulda and Hannover and the approaches thereto out to a distance of 150nm, should be completed at the conclusion of "Day-3". Consistent with the requirement for localized air superiority, maximum possible concentration is to be placed on attacks against Pact fighter-bomber/ground attack capable aircraft that possess the combat radius to operate with these areas. Specifically, the Flogger D/J and the Frogfoot. At the conclusion of "Day-3", the build-up of Central Region ground forces should be sufficient to mount a counter-attack which is scheduled to commence "Day-4".

B. To insure the greatest chance for success of this undertaking, CINCENT has also directed that the build-up of forces be afforded the maximum degree of protection concurrently with offensive operations. Accordingly, all air defense-capable aircraft will be utilized in a defensive counterair role. Apportionment guidance for "Day-1" through "Day-3" is

offensive counterair	45%
interdiction	10%
offensive air support	45%.

ADDITIONAL INFORMATION

For purposes of this experiment:

You will consider only offensive counterair missions against enemy airbases.

Only 16 enemy airbases are considered.

For each enemy airbase only 10 components are described in the Air Installation File.

Only nine enemy aircraft are listed in the Air Order of Battle files.

The target prioritization includes enough enemy airbases and components to require more than 300 F-16 sorties to carry out the attacks.

Please keep in mind:

The purpose of this experiment is to investigate how people would interact with certain kinds of systems. Consequently, although we will be happy to answer any questions you may have about the TPT, there may be some questions we cannot answer until after the experiment is complete. Also, there may be times when you feel that there are some necessary displays that the TPT should have, but doesn't. Please bear with us, this too is part of the experiment. (At the end we will want to know what additional displays you would have liked to have.)

HOW THE TARGET PRIORITIZATION TOOL WORKS

The TPT assigns a target value (priority) to each enemy airbase and recommends components to attack at each airbase. The TPT assigns target values by proceeding through a series of calculations that allow it to estimate the benefit-to-cost ratio for attacking each enemy airbase and components on that airbase. The following pages describe some of the calculations performed by the TPT.

To illustrate these calculation assume that we have the following situation:

1. The only aircraft of interest is the Flogger D/J. Its normal sortie rate is 3 for minimum distance flights of 200 or less. Its maximum range is 400 miles.

2. The airbase HOFT has 10 Flogger D/Js. It is 300 miles from Area of Interest.

3. The Air Installation File indicates the following about HOFT:

# Unsheltered A/C:	Typically around 10
# A/C Shelters:	20
# Revetments:	12
Launch & Recovery Surfaces:	10 aim points
# Command HQs:	2
# Control Sites:	3
# Munition Dumps:	6
# POL Sites:	4
# Maintenance Facilities:	4
# Dumps for Spares:	2

NUMBER OF SORTIES OF INTEREST AT ENEMY AIRBASE

For each a/c of interest calculate:

(#A/C OF INTEREST)*(SORTIE RATE)*(DISTANCE REDUCTION FACTOR)

where the DISTANCE REDUCTION FACTOR is equal to

0 if distance to AOI > MAX DISTANCE,

1 if distance to AOI < MIN DISTANCE,

otherwise,

$$\frac{\text{DISTANCE to AOI - MIN DISTANCE}}{\text{MAX DISTANCE - MIN DISTANCE.}}$$

For example, for HOFT the calculation is

#A/C OF INTEREST	= 10
SORTIE RATE	= 3
DISTANCE REDUCTION FACTOR	= 0.5
# SORTIES OF INTEREST	= 15

F-16s REQUIRED TO ATTACK ENEMY AIR BASE

For each component to be attacked calculate

```
 (# ATTACKS)
*(# F-16s REQ'D FOR PROTOTYPE BASE)
*(ACTUAL CAPACITY)/(PROTOTYPE CAPACITY),
```

and sum over components.

For instance, for HOFT assume a Plan of Attack that involves two attacks on Revetments and one on Launch and Recovery Surfaces:

	Revetments		L&R Surfaces:		
# ATTACKS	2		1		
# F-16 FOR PROTOTYPE	10		17		
ACTUAL CAPACITY	20		12		
PROTOTYPE CAPACITY	10		12		
	-------		-------		
# F-16s REQ'D	40	+	17	=	57

EXPECTED NUMBER OF ENEMY SORTIES REDUCED

For each attack on each component look up (in Effects Knowledge Base) the estimated MAXIMUM REDUCTION and % REDUCTION in sortie rate. For each attack on each component, the REMAINING CAPABILITY is calculated as follows:

$$\text{REMAINING CAPABILITY} = 1 - \frac{\text{MAX REDUCTION}}{100} * \frac{\text{\% REDUCTION}}{100}$$

The EXPECTED NUMBER OF SORTIES REMAINING is

```
   NUMBER OF SORTIES OF INTEREST
 * INITIAL CAPACITY/100
 * REMAINING CAPABILITY AFTER 1st COMPONENT ATTACK
 * REMAINING CAPABILITY AFTER 2nd COMPONENT ATTACK
                 .
                 .
                 .
 * REMAINING CAPABILITY AFTER Mth COMPONENT ATTACK
```

Finally the EXPECTED NUMBER OF SORTIES REDUCED is equal to

```
   NUMBER OF SORTIES OF INTEREST
 - EXPECTED NUMBER OF SORTIES REMAINING.
```

For instance for HOFT, for two attacks against Revetments and one against Launch and Recovery Surfaces we may get

Component	Attack 1 Revetment	Attack 2 Revetment	Attack 3 L&R Surfaces
MAX REDUCTION	25	25	30
% REDUCTION	40	40	50
	--------	--------	---------
	10	10	15

```
# SORTIES OF INTEREST              =  15
INITIAL CAPACITY                   = 100
REMAINING CAPABILITY 1ST ATTACK =  .9
REMAINING CAPABILITY 2ND ATTACK =  .9
REMAINING CAPABILITY 3RD ATTACK =  .85
                                     ------
EXPECTED # SORTIES REMAINING          10.3

EXPECTED NUMBER SORTIES REDUCED = 15 - 10.3
                                = 4.7
```

TARGET PRIORITY

The TARGET PRIORITY of an airbase is determined by calculating the BENEFIT-TO-COST RATIO for attacking the components selected in the Plan of Attack.

The BENEFIT-TO-COST RATIO is equal to

$$\frac{\text{EXPECTED NUMBER OF SORTIES REDUCED}}{(\text{\# F-16s REQ'D} + \text{\# F-111s REQ'D} + 1)/2}$$

For instance, for HOFT for two attacks against Revetments and one against Launch & Recovery Surfaces we get:

```
EXPECTED # OF SORTIES REDUCED =   4.7
NUMBER OF F-16s REQUIRED      =  57
NUMBER OF F-111s REQUIRED     =  28
                               -------
BENEFIT-TO-COST RATIO         =  4.7/[(57+28+1)/2]
                              =   .11
```

The TPT determines the high priority airbases by selecting the airbases and airbase components that maximize BENEFIT-TO-COST RATIOs. HOFT has a very low BENEFIT-TO-COST RATIO. It would have a very low TARGET PRIORITY.

MISSION INPUT

WEATHER CONDITIONS

EFFECT WINDOW

ENEMY AIRCRAFT OF INTEREST

FRIENDLY SORTIES PER DAY

BAD WEATHER IS DEFINED AS SITUATIONS IN WHICH ONE OR BOTH OF THE FOLLOWING CONDITIONS ARE MET:

- LESS THAN 3 MILES VISIBILITY
- LESS THAN 3000 FOOT CEILING

SPECIFY THE DAYS ON WHICH BAD WEATHER IS PREDICTED:

0) TODAY
1) DAY 1
2) DAY 2
4) DAY 4
5) DAY 5
6) DAY 6
7) DAY 7

LIST THE DESIRED DAYS: N/A

SPECIFY THE EFFECT WINDOW

HOW MANY DAYS IN THE FUTURE DO YOU WANT THE EFFECT TO START (FIRST DAY OF PLAN IS DAY 1)? 4

HOW MANY DAYS DO YOU WANT THE EFFECT TO LAST? (MAX = 7): 1

SPECIFY AIRCRAFT OF INTEREST

1) FENCER (FNCR)
2) FLOGGER D/J (FLGR DJ)
3) FLOGGER G/K (FLGR GK)
4) FROGFOOT (FRGFT)
5) FULCRUM (FLCRM)
6) FLANKER (FLNKR)
7) FISHBED H (FSBD H)
8) FOXBAT S (FXBT S)
9) FOXBAT B/D (FXBT BD)

LIST AIRCRAFT TYPES OF INTEREST (BY NUMBER): 2,4

FRIENDLY SORTIES AVAILABLE

THERE ARE 3 PLANNING DAYS.

ENTER THE NUMBER OF FRIENDLY SORTIES
AVAILABLE PER DAY: 280, 280, 280

SUBJECT INFORMATION SHEET

NAME: ____________________

RANK: ____________________

CURRENT ASSIGNMENT: ____________________

YEARS OF EXPERIENCE AS TARGETEER: ________

TIME IN CENTRAL EUROPE: ____________

For each high priority target on each day of the attack:

(1) Indicate by number those factors (from the List of Factors) that you believe contributed significantly to its high value as a target.

(2) Rank the components selected for attack at that airbase according to their relative contribution to the assigned value for that target.

DAY 1

First Priority Target: Mimon

Factors: ____ ____ ____ ____ ____ ____ ____

Component Rank Order:

1. ____________________ 4. ____________________

2. ____________________ 5. ____________________

3. ____________________ 6. ____________________

Second Priority Target: Altenburg

Factors: ____ ____ ____ ____ ____ ____ ____

Component Rank Order:

1. ____________________ 4. ____________________

2. ____________________ 5. ____________________

3. ____________________ 6. ____________________

Third Priority Target: Trollenhagen

Factors: ____ ____ ____ ____ ____ ____ ____

Component Rank Order:

1. ____________________ 4. ____________________

2. ____________________ 5. ____________________

3. ____________________ 6. ____________________

DAY 2

First Priority Target: Trollenhagen

Factors: ____ ____ ____ ____ ____ ____ ____

Component Rank Order:

1. ____________________ 4. ____________________
2. ____________________ 5. ____________________
3. ____________________ 6. ____________________

Second Priority Target: Mimon

Factors: ____ ____ ____ ____ ____ ____ ____

Component Rank Order:

1. ____________________ 4. ____________________
2. ____________________ 5. ____________________
3. ____________________ 6. ____________________

Third Priority Target: Grossenhain

Factors: ____ ____ ____ ____ ____ ____ ____

Component Rank Order:

1. ____________________ 4. ____________________
2. ____________________ 5. ____________________
3. ____________________ 6. ____________________

DAY 3

First Priority Target: Altenburg

Factors: ____ ____ ____ ____ ____ ____ ____

Component Rank Order:

1. ____________________ 4. ____________________
2. ____________________ 5. ____________________
3. ____________________ 6. ____________________

Second Priority Target: Mimon

Factors: ____ ____ ____ ____ ____ ____ ____

Component Rank Order:

1. ____________________ 4. ____________________
2. ____________________ 5. ____________________
3. ____________________ 6. ____________________

Third Priority Target: Trollenhagen

Factors: ____ ____ ____ ____ ____ ____ ____

Component Rank Order:

1. ____________________ 4. ____________________
2. ____________________ 5. ____________________
3. ____________________ 6. ____________________

GENERAL QUESTIONS

A. 1. Which displays helped you most in understanding the system?

2. For each one, why?

B. 1. If you could design the contents and formats of displays that would be "ideal" for you, what would they look like? (Use the blank sheets available.)

2. For each one, why? (Describe below or on corresponding sheets.)

GENERAL QUESTIONS

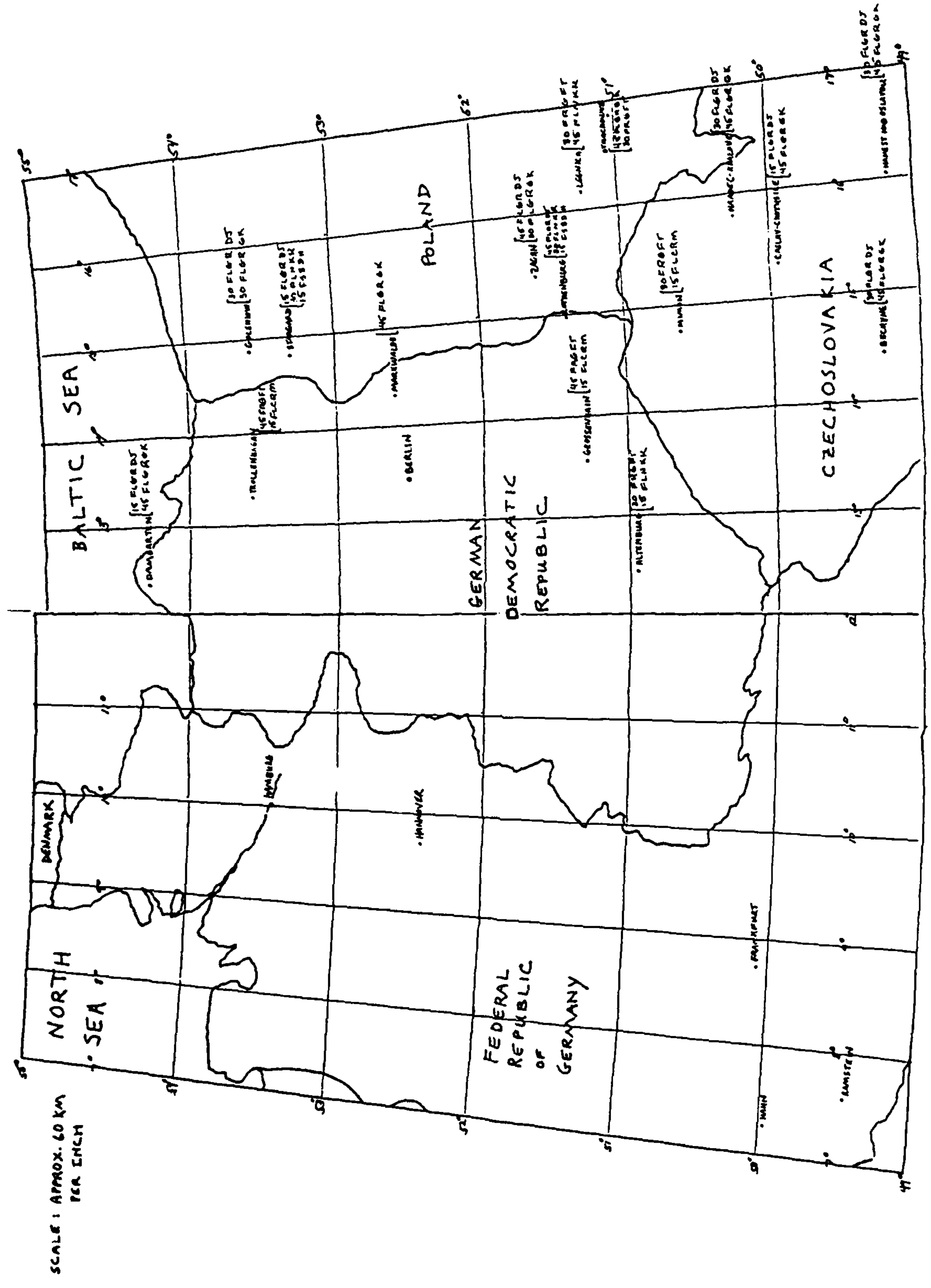
1. How do you define the targeting problem?
   How would you go about solving it?

2. How do you think the aid defines and solves the targeting problem?

3. How do you think an ideal aid could support you in solving the targeting problem?

APPENDIX B

USER-ORIENTED DISPLAYS


NORTH SEA
BALTIC SEA
DENMARK
POLAND
GERMAN DEMOCRATIC REPUBLIC
FEDERAL REPUBLIC OF GERMANY
CZECHOSLOVAKIA
BERLIN
HANNOVER
HAMBURG
FRANKFURT
SCALE: APPROX. 60 KM PER INCH

PRIORITIZATION FOR DAY 1

AIRBASE	ENEMY SORTIES REDUCED, DAY 4	FRIENDLY SORTIES REQ'D F-16 REQ'D	FRIENDLY SORTIES REQ'D F-111 REQ'D	TARGET VALUE BEN/COST*100
GOLENIOW	0.8	11	5	10
NAMEST NAD OSLAVOU	0.0	0	0	0
ZAGAN	2.6	16	8	21
HRADEC-KRALOVE	2.2	20	10	14
ROTHENBURG	2.9	21	11	17
BECHYNE	1.9	16	8	15
CASLAV CHOTUSICE	0.0	0	0	0
STARGARD	0.0	0	0	0
MARXWALD	0.0	0	0	0
ALTENBURG	46.3	75	37	82
LEGNICA	0.0	0	0	0
DAMGARTEN	0.0	0	0	0
TROLLEN HAGAN	21.0	35	18	78
GROSSEN HAIN	36.0	63	31	76
MIMON	37.0	53	27	91
STRACHOWICE	0.0	0	0	0
TOTAL	150.7	310	155	65

PRIORITIZATION FOR DAY 2

AIRBASE	ENEMY SORTIES REDUCED, DAY 4	FRIENDLY SORTIES REQ'D F-16 REQ'D	FRIENDLY SORTIES REQ'D F-111 REQ'D	TARGET VALUE BEN/COST*100
GOLENIOW	0.0	0	0	0
NAMEST NAD OSLAVOU	0.0	0	0	0
ZAGAN	12.9	16	8	103
HRADEC-KRALOVE	8.6	7	4	150
ROTHENBURG	18.7	23	12	104
BECHYNE	0.0	0	0	0
CASLAV CHOTUSICE	0.0	0	0	0
STARGARD	0.0	0	0	0
MARXWALD	0.0	0	0	0
ALTENBURG	88.2	73	38	157
LEGNICA	0.0	0	0	0
DAMGARTEN	1.6	1	1	117
TROLLEN HAGAN	46.6	31	17	189
GROSSEN HAIN	118.1	95	50	162
MIMON	73.6	57	30	168
STRACHOWICE	0.0	0	0	0
TOTAL =	368.3	304	159	159

PRIORITIZATION FOR DAY 3

AIRBASE	ENEMY SORTIES REDUCED, DAY 4	FRIENDLY SORTIES REQ'D F-16 REQ'D	F-111 REQ'D	TARGET VALUE BEN/COST*100
GOLENIOW	0.0	0	0	0
NAMEST NAD OSLAVOU	0.0	0	0	0
ZAGAN	27.1	20	11	169
HRADEC-KRALOVE	20.0	18	10	138
ROTHENBURG	40.0	36	20	141
BECHYNE	15.3	20	11	97
CASLAV CHOTUSICE	0.0	0	0	0
STARGARD	3.7	5	3	86
MARXWALD	0.0	0	0	0
ALTENBURG	90.1	39	24	282
LEGNICA	0.0	0	0	0
DAMGARTEN	3.3	2	1	142
TROLLEN HAGAN	62.4	36	21	215
GROSSEN HAIN	163.7	105	58	199
MIMON	67.5	32	20	254
STRACHOWICE	0.0	0	0	0
TOTAL =	492.9	313	179	200

AIRBASE: MIMON

Note: This is a sample. A similar table was available for each target.

BASIC ENCYCLOPEDIA NO.:	0103-6561129
MAP COORDINATES:	50 37 12 N, 14 43 48 E
DISTANCE TO AOI:	175
#SOI:	98

AIR ORDER OF BATTLE

FENCER (FNCR):	
FLOGGER D/J (FLGR DJ):	
FLOGGER G/K (FLGR GK):	
FROGFOOT (FRGFT):	30
FULCRUM (FLCRM):	15
FLANKER (FLNKR):	
FISHBED H (FSBD H):	
FOXBAT S (FXBT S):	
FOXBAT B/D (FSBT BD):	

AIR INSTALLATION INFORMATION

AIRCRAFT IN OPEN (ACO):	1	(AIRCRAFT)
AIRCRAFT IN SHELTERS (ACS):	20	(SHELTERS)
AIRCRAFT IN REVETMENTS (ACR):	8	(REVETMENTS)
MAINTENANCE FACILITIES (MXF):	4	(FACILITIES)
L & R SURFACES (L&R):	6	(AIMPOINTS)
POL:	5	(AIMPOINTS)
MUNITIONS DUMPS (MUN):	9	
COMMAND HEADQUARTERS (CMD):	2	
CONTROL/RADAR FACILITIES (CNT):	3	
SPARES:	3	

Note: This is a sample. A similar table was available for each target.

					PLAN FOR AIRBASE:				MIMON				ENEMY
											FRIENDLY		SORTIES
DAY OF					COMPONENTS TARGETED						SORTIES REQD		REDUCED
ATTACK	UNS A/C	SHELTERS	RVTMNTS	L&R SFCS	CMD HQ	CTRL	MUNTNS	POL	MAIN FC	SPARES	F-16	F-111	DAY 4
DAY 1			√	√					√		53	27	37.0
DAY 2	√		√	√	√				√		57	30	73.6
DAY 3	√		√		√	√					32	20	67.5

EXPERT ASSESSMENT OF EFFECTS										
% OF MAXIMUM		COMPONENT								
OBTAINED FROM										
ONE ATTACK	UNS A/C	SHELTERS	RVTMNTS	L&R SFCS	CMD HQ	CTRL	MUNTNS	POL	MAIN FC	SPARES
1ST DAY AFTER	100	40	60	40	40	60	5	10	5	5
2ND DAY AFTER	50	25	30	35	20	20	10	50	20	15
3RD DAY AFTER	0	10	15	30	0	0	20	10	40	30
4TH DAY AFTER	0	5	5	10	0	0	10	0	20	40
5TH DAY AFTER	0	0	0	0	0	0	5	0	10	20
MAXIMUM % REDUCTION										
OBTAINABLE FROM										
ONE ATTACK	8%	50%	30%	40%	15%	10%	30%	12%	40%	13%

	EXPERT ASSESSMENT OF A/C CHARACTERISTICS								
	FNCR	FLGR D/J	FLGR G/K	FRGFT	FULCRUM	FLANKER	FSBD H	FXBT S	FXBT B/D
A/C SORTIE RATE	3	2	4	4	5	3	5	3	5
MIN A/C DISTANCE	170	150	200	160	250	250	250	250	270
MAX A/C DISTANCE	950	400	600	240	600	800	435	435	750

	EXPERT ASSESSMENT OF SORTIES REQUIRED FOR ATTACK									
	UNS A/C	SHELTERS	RVTMNTS	L&R SFCS	CMD HQ	CTRL	MUNTNS	POL	MAIN FC	SPARES
PROTO CAPACITY	5	20	6	4	2	2	6	4	3	1
F-16 REQ'D	6	60	6	16	4	4	24	24	8	4
F-111 REQ'D	3	30	3	8	3	3	12	12	4	2

APPENDIX C

AID-ORIENTED DISPLAYS

	PRIORITIZATION FOR DAY 1		
	ENEMY SORTIES	FRIENDLY SORTIES REQ'D		TARGET VALUE
AIRBASE	REDUCED, DAY 4	F-16 REQ'D	F-111 REQ'D	BEN/COST*100
GOLENIOW	0.8	11	5	10
NAMEST NAD OSLAVOU	0.0	0	0	0
ZAGAN	2.6	16	8	21
HRADEC-KRALOVE	2.2	20	10	14
ROTHENBURG	2.9	21	11	17
BECHYNE	1.9	16	8	15
CASLAV CHOTUSICE	0.0	0	0	0
STARGARD	0.0	0	0	0
MARXWALD	0.0	0	0	0
ALTENBURG	46.3	75	37	82
LEGNICA	0.0	0	0	0
DAMGARTEN	0.0	0	0	0
TROLLEN HAGAN	21.0	35	18	78
GROSSEN HAIN	36.0	63	31	76
MIMON	37.0	53	27	91
STRACHOWICE	0.0	0	0	0
TOTAL	150.7	310	155	65

PRIORITIZATION FOR DAY 2

AIRBASE	ENEMY SORTIES REDUCED, DAY 4	FRIENDLY SORTIES REQ'D F-16 REQ'D	FRIENDLY SORTIES REQ'D F-111 REQ'D	TARGET VALUE BEN/COST*100
GOLENIOW	0.0	0	0	0
NAMEST NAD OSLAVOU	0.0	0	0	0
ZAGAN	12.9	16	8	103
HRADEC-KRALOVE	8.6	7	4	150
ROTHENBURG	18.7	23	12	104
BECHYNE	0.0	0	0	0
CASLAV CHOTUSICE	0.0	0	0	0
STARGARD	0.0	0	0	0
MARXWALD	0.0	0	0	0
ALTENBURG	88.2	73	38	157
LEGNICA	0.0	0	0	0
DAMGARTEN	1.6	1	1	117
TROLLEN HAGAN	46.6	31	17	189
GROSSEN HAIN	118.1	95	50	162
MIMON	73.6	57	30	168
STRACHOWICE	0.0	0	0	0
TOTAL =	368.3	304	159	159

PRIORITIZATION FOR DAY 3				
	ENEMY SORTIES	FRIENDLY SORTIES REQ'D		TARGET VALUE
AIRBASE	REDUCED, DAY 4	F-16 REQ'D	F-111 REQ'D	BEN/COST*100
GOLENIOW	0.0	0	0	0
NAMEST NAD OSLAVOU	0.0	0	0	0
ZAGAN	27.1	20	11	169
HRADEC-KRALOVE	20.0	18	10	138
ROTHENBURG	40.0	36	20	141
BECHYNE	15.3	20	11	97
CASLAV CHOTUSICE	0.0	0	0	0
STARGARD	3.7	5	3	86
MARXWALD	0.0	0	0	0
ALTENBURG	90.1	39	24	282
LEGNICA	0.0	0	0	0
DAMGARTEN	3.3	2	1	142
TROLLEN HAGAN	62.4	36	21	215
GROSSEN HAIN	163.7	105	58	199
MIMON	67.5	32	20	254
STRACHOWICE	0.0	0	0	0
TOTAL =	492.9	313	179	200

PLAN OF ATTACK, DAY 1

AIRBASE	COMPONENTS									
	UNS A/C	SHELTERS	RVTMNTS	L&R SFCS	CMD HQ	CTRL	MUNTNS	POL	MAIN FC	SPARES
GOLENIOW									√	
NAMEST NAD OSLAVOU										
ZAGAN									√	
HRADEC-KRALOVE									√	√
ROTHENBURG									√	
BECHYNE									√	
CASLAV CHOTUSICE										
STARGARD										
MARXWALD										
ALTENBURG			√	√					√	√
LEGNICA										
DAMGARTEN										
TROLLEN HAGAN			√						√	√
GROSSEN HAIN				√					√	
MIMON			√	√					√	
STRACHOWICE										

PLAN OF ATTACK, DAY 2

			COMPONENTS						
AIRBASE	UNS A/C	SHELTERS	RVTMNTS	L&R SFCS	CMD HQ	CTRL	MUNTNS	POL	MAIN FC	SPARES
GOLENIOW										
NAMEST NAD OSLAVOU										
ZAGAN			√						√	
HRADEC-KRALOVE			√							
ROTHENBURG			√		√				√	
BECHYNE										
CASLAV CHOTUSICE										
STARGARD										
MARXWALD										
ALTENBURG	√		√	√	√	√			√	
LEGNICA										
DAMGARTEN	√									
TROLLEN HAGAN	√		√		√				√	
GROSSEN HAIN	√		√	√	√				√	
MIMON	√		√	√	√				√	
STRACHOWICE										

PLAN OF ATTACK, DAY 3

				COMPONENTS						
AIRBASE	UNS A/C	SHELTERS	RVTMNTS	L&R SFCS	CMD HQ	CTRL	MUNTNS	POL	MAIN FC	SPARES
GOLENIOW										
NAMEST NAD OSLAVOU										
ZAGAN			√		√					
HRADEC-KRALOVE			√		√					
ROTHENBURG	√		√		√	√				
BECHYNE	√		√		√					
CASLAV CHOTUSICE										
STARGARD			√							
MARXWALD										
ALTENBURG	√		√		√	√				
LEGNICA										
DAMGARTEN	√									
TROLLEN HAGAN	√		√		√	√				
GROSSEN HAIN	√		√	√	√	√				
MIMON	√		√		√	√				
STRACHOWICE										

EXPERT ASSESSMENT OF A/C CHARACTERISTICS

	FNCR	FLGR D/J	FLGR G/K	FRGFT	FULCRUM	FLANKER	FSBD H	FXBT S	FXBT B/D
A/C SORTIE RATE	3	2	4	4	5	3	5	3	5
MIN A/C DISTANCE	170	150	200	160	250	250	250	250	270
MAX A/C DISTANCE	950	400	600	240	600	800	435	435	750

EXPERT ASSESSMENT OF SORTIES REQUIRED FOR ATTACK

	UNS A/C	SHELTERS	RVTMNTS	L&R SFCS	CMD HQ	CTRL	MUNTNS	POL	MAIN FC	SPARES
PROTO CAPACITY	5	20	6	4	2	2	6	4	3	1
F-16 REQ'D	6	60	6	16	4	4	24	24	8	4
F-111 REQ'D	3	30	3	8	3	3	12	12	4	2

EXPERT ASSESSMENT OF EFFECTS

% OF MAXIMUM OBTAINED FROM ONE ATTACK	COMPONENT									
	UNS A/C	SHELTERS	RVTMNTS	L&R SFCS	CMD HQ	CTRL	MUNTNS	POL	MAIN FC	SPARES
1ST DAY AFTER	100	40	60	40	40	60	5	10	5	5
2ND DAY AFTER	50	25	30	35	20	20	10	50	20	15
3RD DAY AFTER	0	10	15	30	0	0	20	10	40	30
4TH DAY AFTER	0	5	5	10	0	0	10	0	20	40
5TH DAY AFTER	0	0	0	0	0	0	5	0	10	20
MAXIMUM % REDUCTION OBTAINABLE FROM ONE ATTACK	8%	50%	30%	40%	15%	10%	30%	12%	40%	13%

AIR ORDER OF BATTLE

A/C AT BASE	FNCR	FLGR D/J	FLGR G/K	FRGFT	FULCRUM	FLANKER	FSBD H	FXBT S	FXBT B/D
GOLENIOW	0	30	30	0	0	0	0	0	0
NAMEST NAD OSLAVOU	0	30	45	0	0	0	0	0	0
ZAGAN	0	45	30	0	0	0	0	0	0
HRADEC-KRALOVE	0	30	45	0	0	0	0	0	0
ROTHENBURG	0	45	0	0	0	30	15	0	0
BECHYNE	0	30	45	0	0	0	0	0	0
CASLAV CHOTUSICE	0	15	45	0	0	0	0	0	0
STARGARD	0	15	0	0	0	30	15	0	0
MARXWALD	0	0	45	0	0	0	0	0	0
ALTENBURG	0	0	0	30	0	15	0	0	0
LEGNICA	0	0	0	30	0	45	0	0	0
DAMGARTEN	0	15	45	0	0	0	0	0	0
TROLLEN HAGAN	0	0	0	45	15	0	0	0	0
GROSSEN HAIN	0	0	0	45	15	0	0	0	0
MIMON	0	0	0	30	15	0	0	0	0
STRACHOWICE	0	0	45	30	0	0	0	0	0

	OTHER INFORMATION	
	DIST BASE TO AOI	NUMBER SORTIES OF INTEREST
GOLENIOW	230	41
NAMEST NAD OSLAVOU	240	38
ZAGAN	220	65
HRADEC-KRALOVE	200	48
ROTHENBURG	200	72
BECHYNE	200	48
CASLAV CHOTUSICE	200	24
STARGARD	230	20
MARXWALD	200	0
ALTENBURG	100	120
LEGNICA	250	0
DAMGARTEN	230	20
TROLLEN HAGAN	200	90
GROSSEN HAIN	125	180
MIMON	175	98
STRACHOWICE	250	0
	TOTAL =	864

AIR INSTALLATION DATA

	UNS A/C	SHELTERS	RVTMNTS	L&R SFCS	CMD HQ	CTRL	MUNTNS	POL	MAIN FC	SPARES
				COMPONENTS						
GOLENIOW	4	16	11	7	2	2	11	6	4	3
NAMEST NAD OSLAVOU	10	40	13	7	2	4	15	8	6	3
ZAGAN	8	22	8	10	2	3	13	6	3	3
HRADEC-KRALOVE	7	20	7	4	2	3	12	6	3	1
ROTHENBURG	8	20	8	7	2	3	13	6	4	2
BECHYNE	3	26	12	4	2	3	10	5	3	2
CASLAV CHOTUSICE	6	20	8	10	2	3	14	6	4	3
STARGARD	9	20	5	8	2	3	11	6	5	2
MARXWALD	4	30	7	9	2	3	10	5	3	2
ALTENBURG	3	20	8	8	2	2	13	5	5	2
LEGNICA	5	20	8	4	2	3	11	6	5	2
DAMGARTEN	1	22	9	4	2	3	13	5	5	4
TROLLEN HAGAN	4	20	6	10	2	3	12	5	4	1
GROSSEN HAIN	2	60	20	9	2	4	12	5	5	4
MIMON	1	20	8	6	2	3	9	5	4	3
STRACHOWICE	8	11	8	8	2	2	10	6	4	3

APPENDIX D

CORRECT RESPONSES

LIST OF FACTORS

1. Relatively short distance between airbase and Area of Interest
2. Relatively high capacity of components selected for attack (e.g., relatively more shelters).
3. Airbase contains relatively more enemy a/c of interest.
4. Relatively low capacity of components selected for attack (e.g., relatively fewer shelters).
5. Relatively low number of friendly sorties required to attack selected components.
6. Relatively high sortie rate of a/c of interest at enemy airbase.
7. Relatively high % reduction in sortie rate for attacking selected components.

---

1. Yes if distance less than 200
   No if distance greater than 200
   ? if distance equals 200

2. No always

3. Yes if 45 a/c of interest
   No if 15 or Ø a/c of interest
   ? if 30 a/c of interest

4. Yes if capacity less than average of the 16 airbases
   No if capacity more than average of the 16 airbases
   ? if capacity equals the average of the 16 airbases

5. Discarded--redundant with #4.

6. Yes if airbase contains only Frogfoots
   No if airbase contains only Flogger D/J's
   ? if airbase contains both

7. No always

DAY 1

First Priority Target: Mimon

Factors:	Yes	No	?	Yes	?	Yes	No
	1	2	3	4	5	6	7

Component Rank Order:

1.	MAIN FC	4.	
2.	RVTMNTS	5.	
3.	L&R SFCS	6.	

Second Priority Target: Altenburg

Factors:	Yes	No	?	?	?	Yes	No

Component Rank Order:

1.	MAIN FC	4.	L&R SFCS
2.	RVTMNTS	5.	
3.	SPARES	6.	

Third Priority Target: Trollenhagen

Factors:	?	No	Yes	Yes	?	Yes	No

Component Rank Order:

1.	MAIN FC	4.	
2.	SPARES	5.	
3.	RVTMNTS	6.	

DAY 2

First Priority Target: Trollenhagen

Factors:

1	2	3	4	5	6	7
?	No	Yes	Yes	?	Yes	No

Component Rank Order:

1. RVTMNTS
2. UNS A/C
3. MAIN FC
4. CMD HQ
5. ________
6. ________

Second Priority Target: Mimon

Factors: Yes No ? Yes ? Yes No

Component Rank Order:

1. UNS A/C
2. RVTMNTS
3. MAIN FC
4. CMD HQ
5. L&R SFCS
6. ________

Third Priority Target: Grossenhain

Factors: Yes No Yes No ? Yes No

Component Rank Order:

1. UNS A/C
2. CMD HQ
3. MAIN FC
4. RVTMNTS
5. L&R SFCS
6. ________

DAY 3

First Priority Target: Altenburg

Factors: Yes No ? Yes ? Yes No

Component Rank Order:

1. RVTMNTS
2. UNS A/C
3. CMD HQ
4. CTRL
5.
6.

Second Priority Target: Mimon

Factors: Yes No ? ? ? Yes No

Component Rank Order:

1. UNS A/C
2. RVTMNTS
3. CMD HQ
4. CTRL
5.
6.

Third Priority Target: Trollenhagen

Factors: ? No Yes ? ? Yes No

Component Rank Order:

1. RVTMNTS
2. UNS A/C
3. CMD HQ
4. CTRL
5.
6.

☆U.S. Government Printing Office: 1989 — 748-002/00215